

36 are FETs. The circuit could potentially be reversed so that the FETs 36 are on the positive side of the bridge in parallel with diodes 32. It would also be possible to eliminate the diodes 34 that are in parallel with the FETs 36. Another possible configuration would be to use six FETs, so that there is a set of switches on the positive 5 side of the bridge and a set on the negative side. If six FETs are used, then it would be possible to eliminate diodes completely. The use of six FETs would provide an additional advantage that the output power could be actively rectified on both the positive and negative sides of the circuit. The output of the bridge is a DC voltage that is applied to a battery bank 37. The battery bank 37 can be connected to heaters, water pumps, 10 appliances, or other devices that utilize electricity.

The FETs 36 are controlled to create an active rectifier. By momentarily shorting all three FETs 36 at the same time, the voltage builds up in the internal inductance of the alternator's windings 18 so that the alternator can be operated in a boost mode. Control of the FETs 36 is performed by a set of gate drivers 38. Gate drivers 38 receive input 15 from a speed sensor 16 and from a voltage sensor 40. The voltage sensor 40 measures the DC output voltage from the bridge and compares it to a reference voltage. The voltage measurement is preferably performed during time periods when all of the FETs 36 are shorted so that the battery voltage is not masked. During the period when the FETs 36 are shorted for battery voltage sensing, the controller waits a short period of 20 time to allow dynamic effects of capacitance and inductance in the circuit to settle out before the battery voltage is sensed. A capacitor could be added to the circuit on the DC side of the bridge in parallel with the battery bank in order to smooth transients in output, although the capacitor can tend to mask the charge state of the batteries 37.

Figure 6 shows a second preferred embodiment of the invention in which the battery bank 37 is replaced with an inverter 42. The inverter 42 provides AC output that can be used to power AC appliances or can be provided to the electricity grid. The inverter 42 utilized with this embodiment of the present invention differs from typical inverters in that it does not include a voltage boost function. A typical inverter must first boost the DC voltage before the power can be inverted into AC output. However, the controller of the present invention can provide DC power at any voltage required. It may potentially be even more advantageous to include a capacitor in the DC portion of the circuit before the inverter in order to provide smooth, steady DC power to the inverter.

Figure 7 shows a typical output of the controller for Phase A of the alternator when boost mode is activated. In this figure, the curve labeled 50 is a square wave at the synchronous speed or the alternator's rotor. 52 is the output voltage from the controller. Note that the output 52 is relatively smooth and does not include the ripple that is typically associated with a conventional prior art rectifier. Curve 54 is the Phase A voltage which is varying at the switching frequency of the FET connected to Phase A. The Phase A voltage is approximately a square wave at the FET's switching frequency modulated by a square wave at the synchronous frequency of the alternator. Curve 56 is the current in Phase A. Note that the current and voltage in Phase A are very closely aligned, thereby resulting in a very high power factor.

The windings of the alternator have been found to make an audible buzz at the FETs' switching frequency. At high winds, this is not important because there is enough aerodynamic noise to mask the buzzing. However, at low wind speeds, the aerodynamic noise is low and does not mask the buzzing in the windings. Noise is a subjective issue

and the degree of annoyance that a noise creates in the person hearing the noise depends on the character of the noise. Tonal noises have been found to be particularly bothersome because they stand out relative to atonal white noise. The buzzing in the alternator's windings is a tonal noise that can be annoying to people who hear it. In order to

5 minimize the effect of the noise, the switching frequency of the FETs is continually modified. In the preferred embodiment, the switching frequency is changed every 1.6 milliseconds. Figure 8 shows the output of the controller and is similar in all respects except that the switching frequency of the FETs has been decreased. Note that the frequency of the square wave in curve 54 is at a lower frequency compared to Figure 7.

10 The gate drivers 38 control the switching of the FETs 36 to achieve the desired output characteristics and to optimize performance of the wind turbine 2. The primary variable that the gate drivers control is the duty cycle of the FETs. A higher duty cycle results in increased voltage boost. Higher duty cycle can also create a higher torque load on the alternator. The duty cycle is determined based upon an operating strategy that is

15 defined based on the wind turbine design including the rotor size, the blade design, alternator characteristics, and controller characteristics. The operating strategy should take into account at least the speed of the wind turbine's rotor and the battery voltage (or line voltage in the case of a grid connected wind turbine with an inverter).

20 The preferred operating strategy has four operating regions which relate to various states of the wind turbine and the controller as shown in Figure 9. The four operating regions are referred to herein as Region 1, Region 2, Region 3, and Region 4. Region 1 occurs when the wind is too low for generation and the wind turbine has not yet started producing power. Region 2 occurs when the wind turbine has begun producing